NGST Tech Challenge Presentation

"Development of Improved Si:As IBC IR Arrays"

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Outline

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Introduction & Rationale

NASA's Origins program -- to explore fundamental questions about the formation and evolution of galaxies, stars, and planets -- has recognized the power of sensing in the 5 - 20 µm range

NGST, as the first infrared-based mission in the Origin plan, baselines the near IR (1 - 5 µm), but

NGST capabilities would be "greatly enhanced" (Dressler Committee) by the inclusion of a high-sensitivity 5 - 20 µm (thermal infrared, TIR) band

NGST requirements exceed the SOA in TIR format and sensitivity

Si:As impurity band conduction (IBC) array and readout technology has been shown to meet the challenging goals of the SIRTF mission

- -sensitivity
- -radiation immunity

Evolutionary improvements of the SIRTF low-background technology base seem a good means to try to meet NGST (& other Origins) goals

NGST TIR Focal Plane Requirements

Parameter	NGST Goal	Improvement Factor (over SIRTF)
1- 5 µm		
Format	2k x 2 k, to 4 k x 4 k	4 - 16 x pixels
	2k x 2 k, to 4 k x 4 k	64 - 256 x pixels
Quantum Efficiency (%)	>90	1+ x
Read Noise (e^-)	3	3 x
Dark Current (e^-/s)	0.01 - 0.1	10 x
Rad Hardness	Useful between 1 - 5 AU	?
5 - 20 µm	(5 - 20 µm)	
Format	1k x 1 k (2 k x 2 k?)	4+ x
Quantum Efficiency (%)	>70	2x
Read Noise (e^-)	~3	15 x
Dark Current (e^-/s)	0.05 (res ~1000) to <10 (res ~3)	1 - 200 x
Rad Hardness	Useful between 1 - 5 AU	?
Precision & Stability	?	?

TIR

Sources: Discussion with H. S. Stockman, (2/96); NGST study kickoff meeting handout, 2/21/96; Astrotech workshop proceedings (1991); ExNPS presentation package, (11/95)

Key Challenges

Relative to SIRTF / low-background state of the art, key development challenges for NGST identified as:

- **Dark current: 1 - 200 x. Drives arrays to extremely low leakage designs, very high purity, and/or lower temperatures.**

- **Read noise: 3 - 15 x. Presses basic noise properties of integrating FET, of selected front-end circuit, and multiplexing characteristics of readout**

- **Format: 4 x or more. Implies very large die size (to 30 mm?), and/or close-packed “mosaicing” approach**

Development Approach

Build upon SBRC SIRTF IBC technology base:
- **optimized Si:As IBC structures**
- **low-noise, cryoCMOS epi readouts (CRC-744)**

Utilize CRC-744 design, *closely coordinating with InSb effort*, to achieve
- **quieter, lower-leakage readouts**
- **larger formats (512 x 512, 1024 x 1024?)**

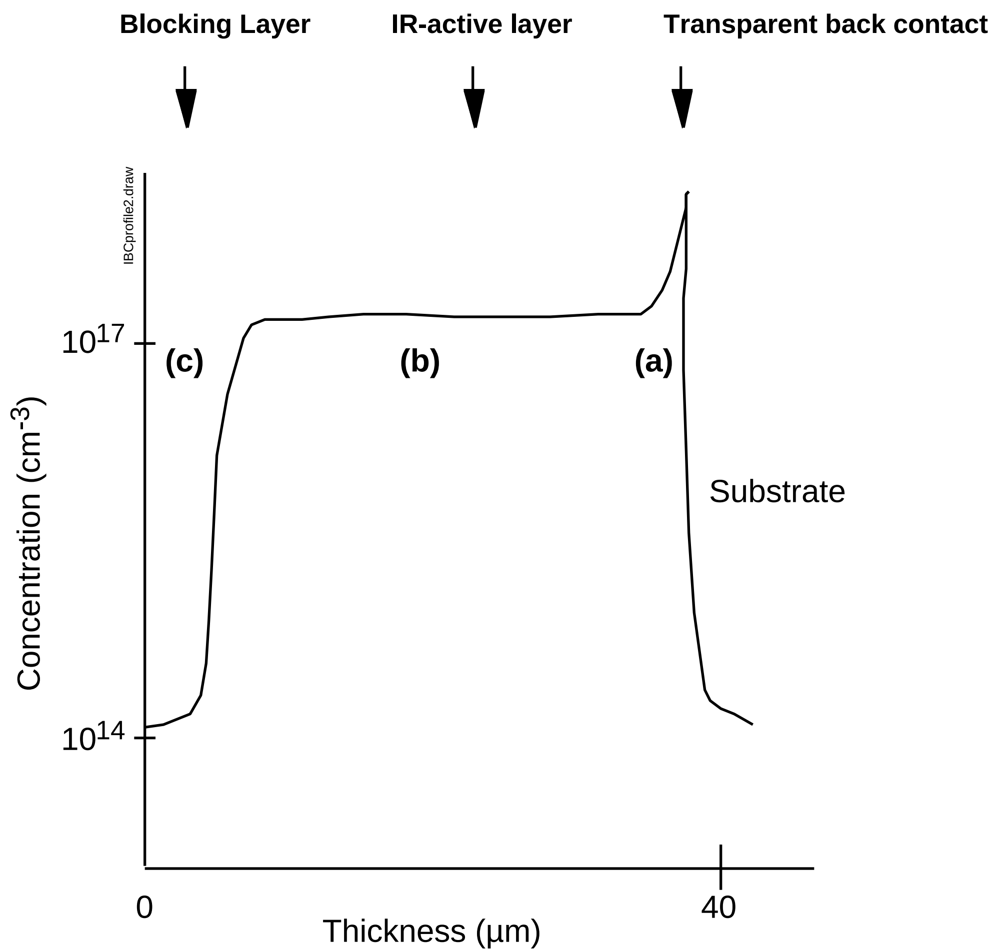
Conduct detailed analytical and experimental studies, to better understand and reduce effects of limiting noise and dark current mechanisms

Produce and evaluate test structures. Complete multiple (3) iterations / lots, leading to optimized hybrid arrays

Improve the art & science of low-background radiometry -- to <0.05 ph/s

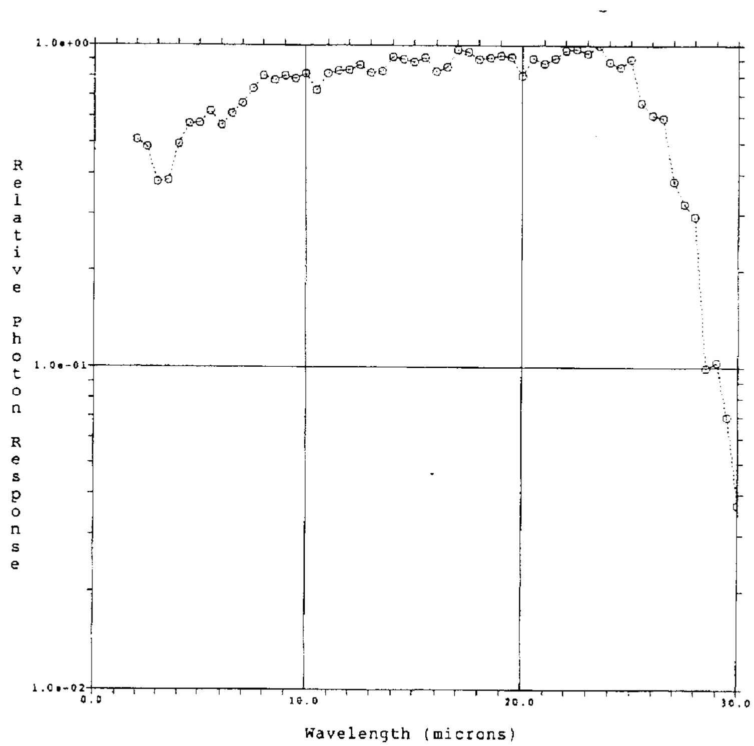
Advanced Si:As IBC
Arrays for NGST

IBC Detector Doping Profile



Si:As IBC Spectral Response

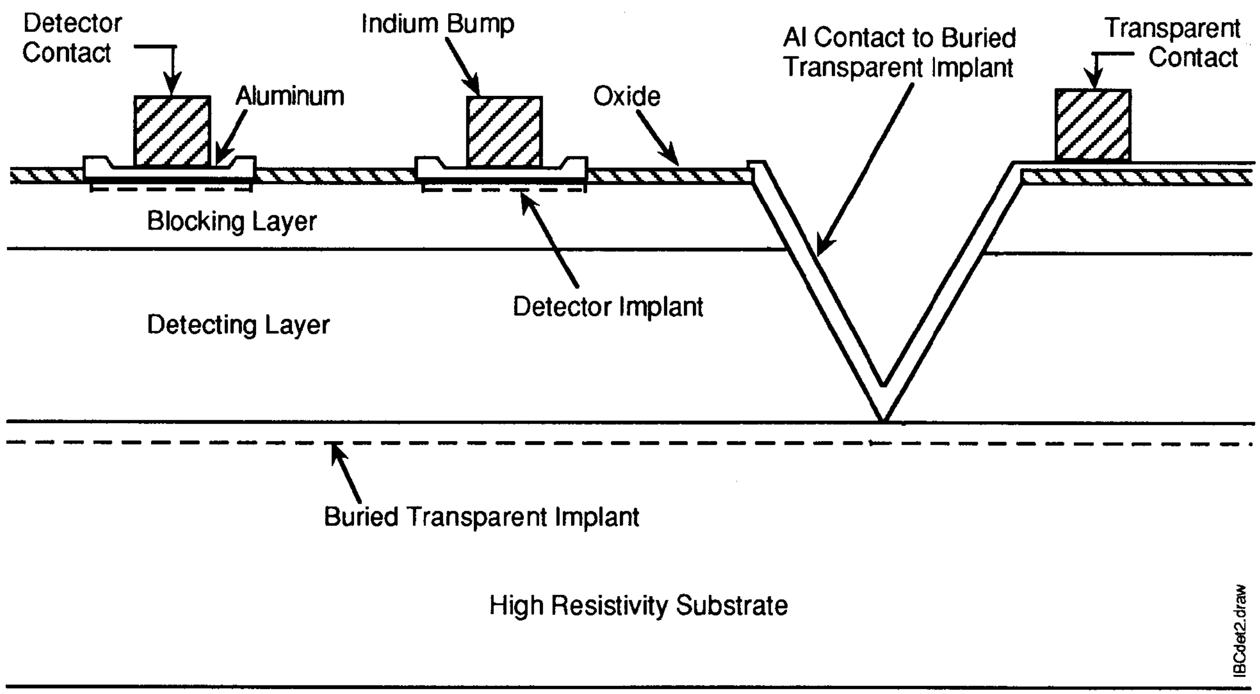
Excellent spectral coverage



NGST TIR Range

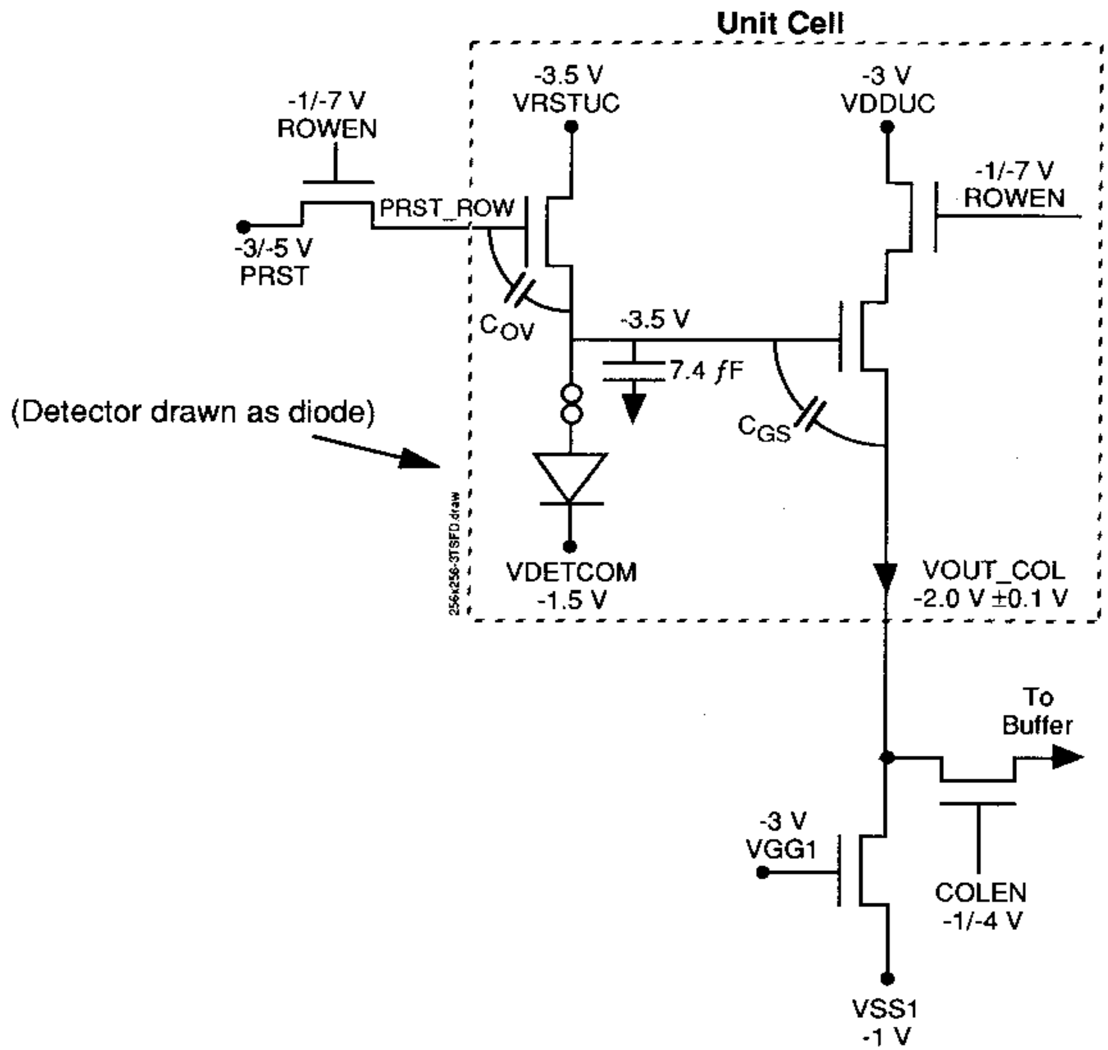
Advanced Si:As IBC
Arrays for NGST

Hybrid IBC Array Structure



Advanced Si:As IBC Arrays for NGST

CRC-744 Cryogenic Readout Circuit



Technical Approach

Optimize IBC Detector Substrate

- -IR active layer (thickness, doping concentrations (donors, residual acceptors <1E12 cm^-3)
- -Blocking layer (thickness, purity)
- -Sharpness of layer transitions
- -Characteristics of buried contact region
- -Epitaxial growth schedules
- -Materials properties (crystallinity, defects, etc.)
- -Surface properties
- -Antireflection coatings
- -Bias / gain optimization

Optimize cryoCMOS Readout Substrate

- -Epi layer (thickness, purity)
- -Epitaxial growth & processing schedules
- -Materials & surface properties (crystallinity, defects, etc.)
- -Input circuit variations (coupled with InSb program)
- -Bias optimization
- -Multiple-sample strategies (Fowler & other)

Development Team

Utilize established expertise and equipment for development and characterization

- **SBRC: device analysis, design, processing, fabrication, hybridization, test**

- **NASA Ames: collaboration on device optimization. Detailed low-background chararacterization. Radiation (gamma and proton) testing**

- **Cornell University: corroborative low-background lab testing. Potential demonstration in spectrometric instrumentation**

Program Objectives

Within a three-year period, demonstrate large-format Si:As IBC arrays which meet or closely approach challenging NGST goals

Format	512 x 512, or 1024 x 1024
Read Noise	3 e^- (multiple sampling allowed)
Dark Current	<0.05 e^-/s for spectroscopy; <10 e^-/s for imaging
Detective Quantum Efficiency	>40%
Operating Temperature	7 - 8 K (higher the better)
Power Dissipation	<1 mW
Pixel Size	~ 30 µm
Spectral Emphasis	5 - 20 µm for NGST

Collect and publish data from multiple labs which demonstrate objectives have been met

Involve astronomical community

Demonstrate full formats for NGST TIR arrays are feasible, likely through test of mosaiced 512 x 512 hybrid arrays. Test for system sensitivity, and degradation effects, e.g., glow, crosstalk.

Recent Supporting Data

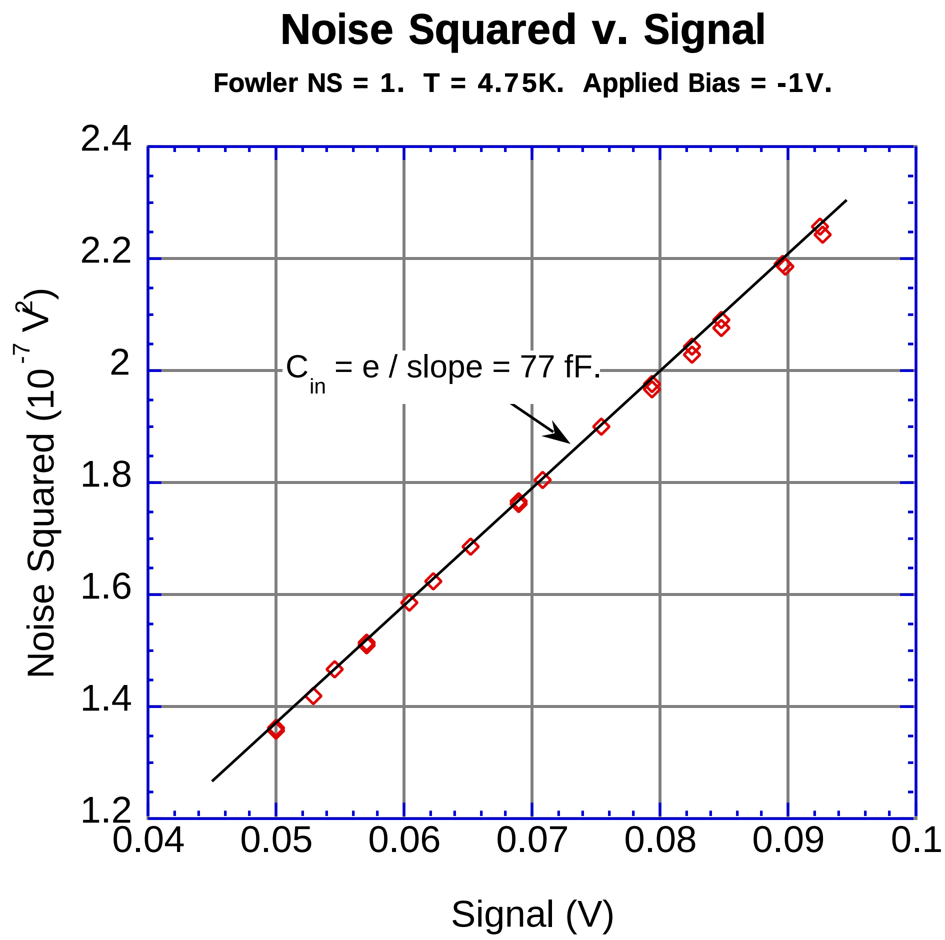
Si:As 256 x 256-element IBC arrays on Hughes/SBRC CRC-744 readouts:

- Data from January 1997 SIRTF Infrared Array Camera (IRAC) Preliminary Design Review (w/ some CRC-644 data)
- Data from June 1997 IRAC Progress Review

CRC-744 IBC Input Capacitance

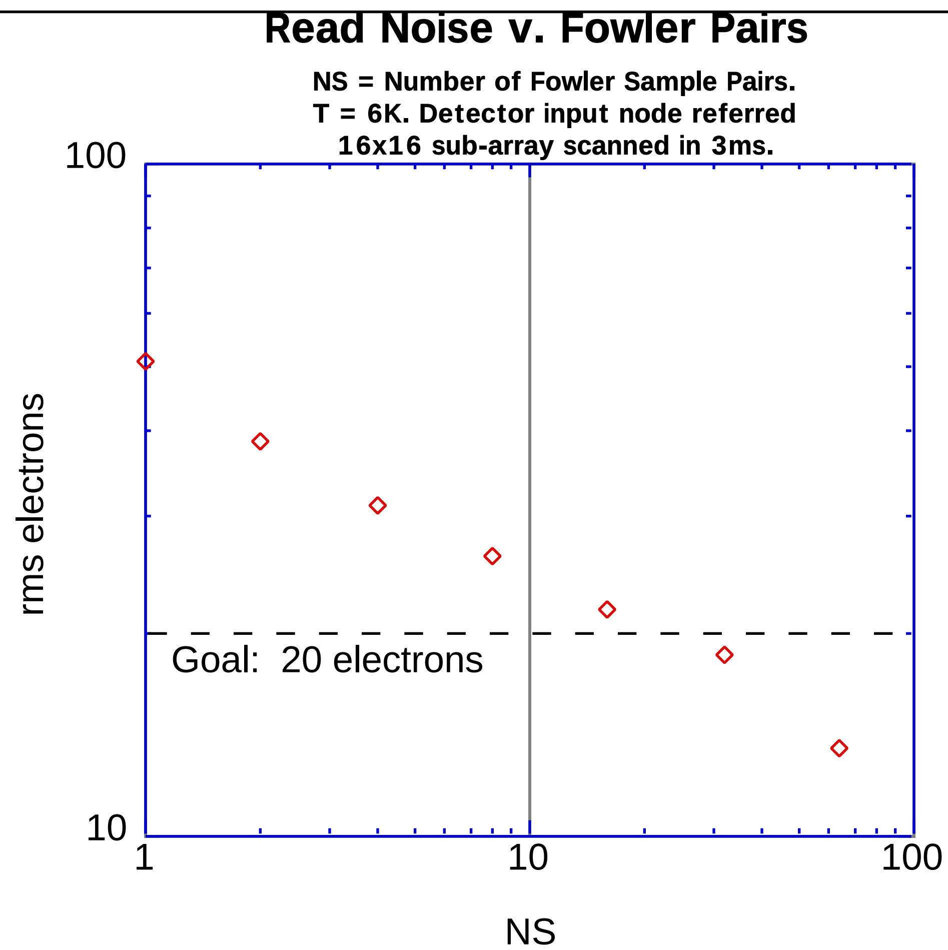
- **Key proportionality factor**

- **Initial value of 77 fF (1.6 µV/e-) at 4.75 K**



CRC-744 Noise vs. Number of Samples

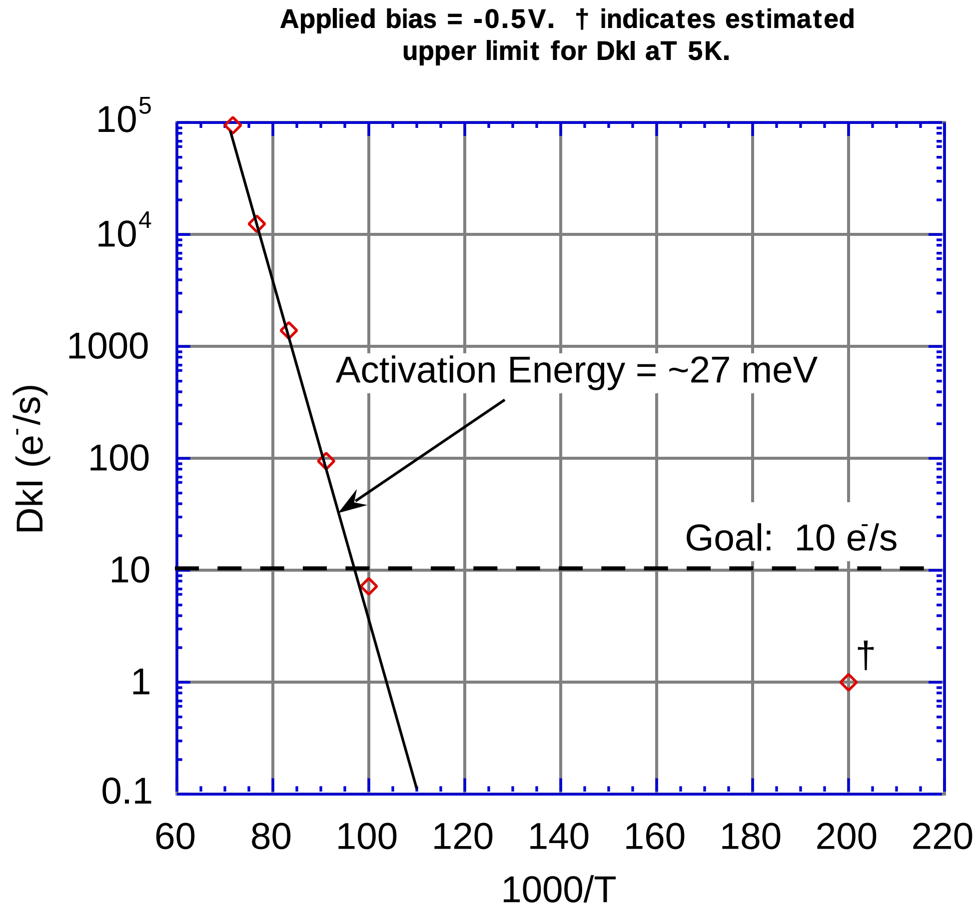
- **Approach: compute standard deviation on series of ~50 sequential frames, on a pixel basis. Compute array-average.**
- **Initial CDS (NS = 1) data point: 50 e-; comparable to best CRC-644 data**
- **Best noise: ~12 e- for NS = 64**
- **Noise clearly drops with multiple samples, but not quite as 1/√NS**



CRC-744 Dark Current vs. 1000/T

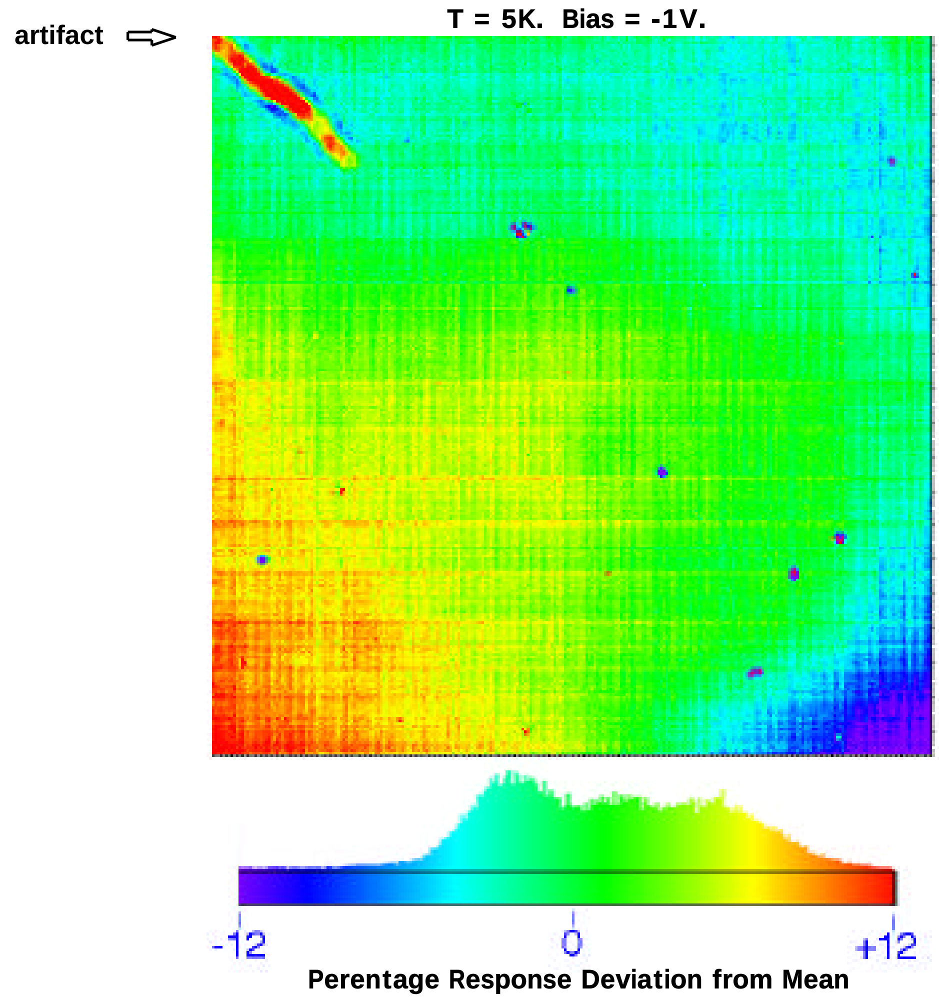
- **Initial value of activation energy reasonable: 27 meV**
- **Initial dark current plot shows IRAC goal (10 e-/s) reachable at 10 K**
- **5 K dark current un-measurably low at integration times as long as 300 s.**

Dark Current v. Inverse Temperature



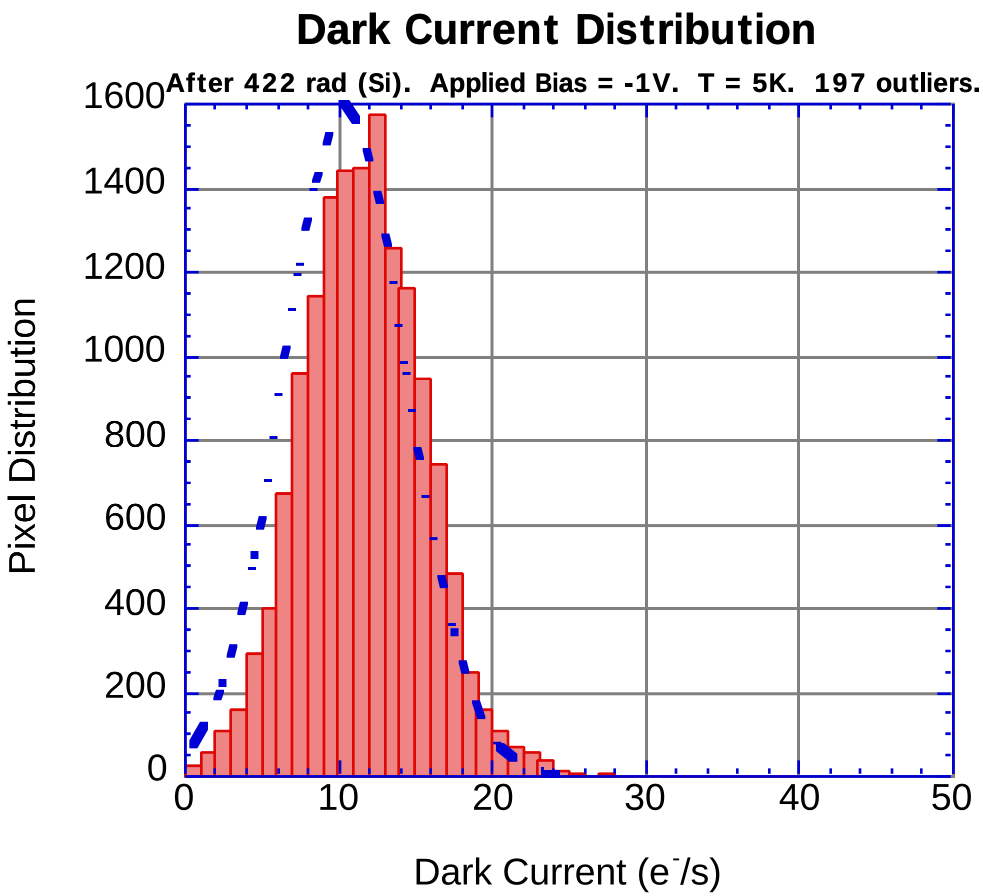
CRC-644 IBC Uniformity

- **Excellent uniformity (5.5% 1 σ)**
- **Excellent operability (99.94%)**
- **'Defect' in upper-left is a fiber in FOV**



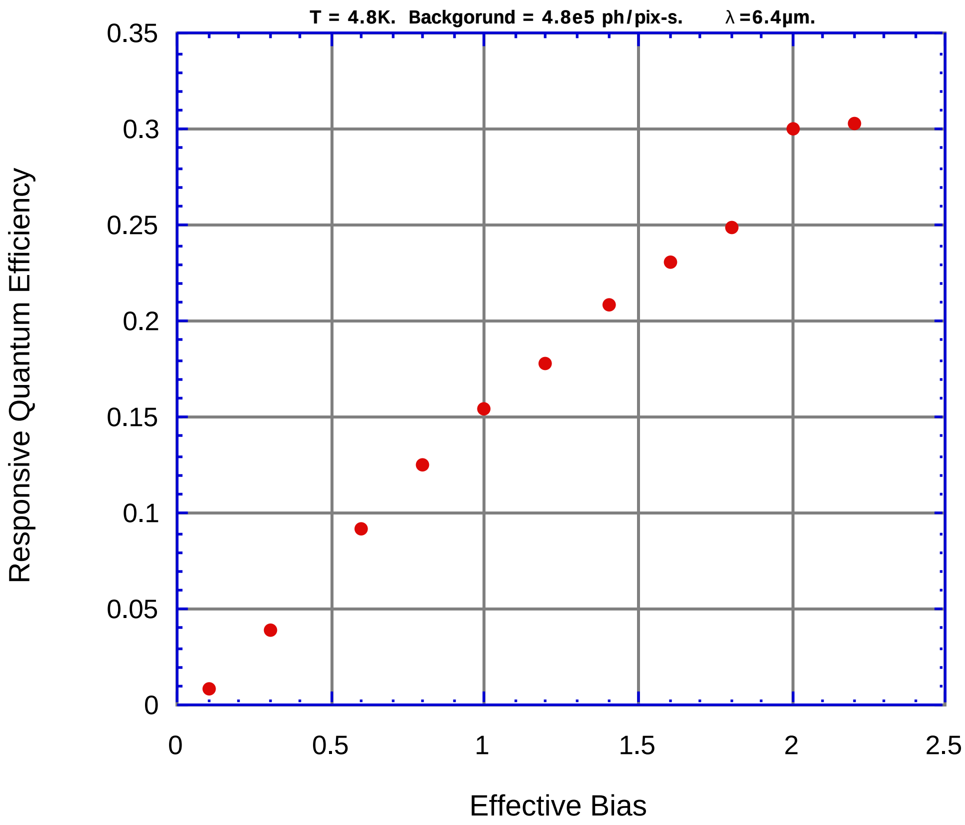
CRC-644 Proton Radiation Effects

- 1. Activated dark current
  - Approx 1 % of pixels activated
  - Annealing and time (order of min) restores almost all leaky pixels
- 2. Responsivity
  - Responsivity does not change measurably, even after largest dose
- 3. Noise effects
  - No measurable long-term effects

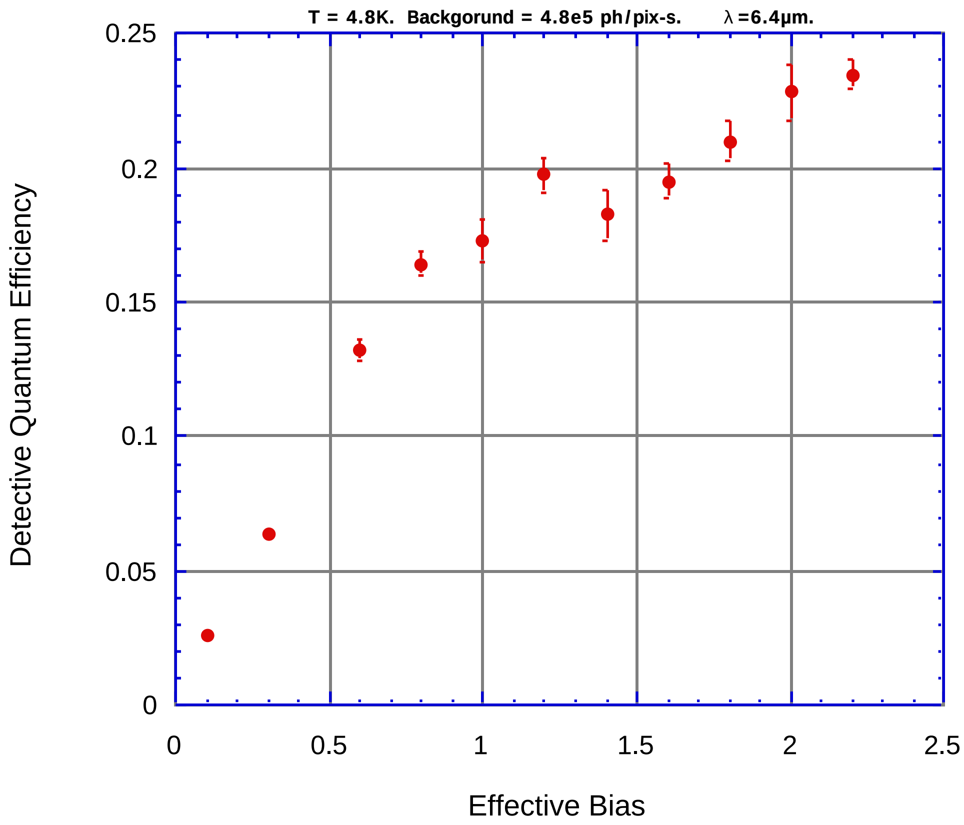


Advanced Si:As IBC
Arrays for NGST

Responsive QE on Part IBC 65740 (June ‘97 Data)

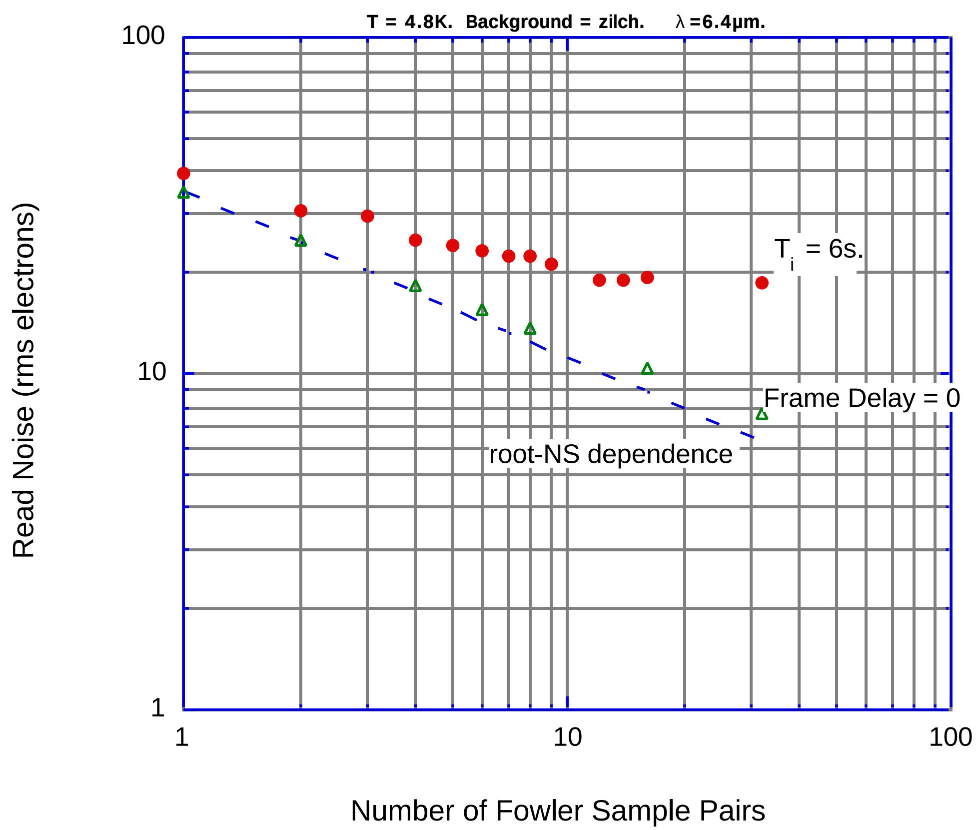


Detective QE on Part IBC 65740 (June '97 Data)



Advanced Si:As IBC
Arrays for NGST

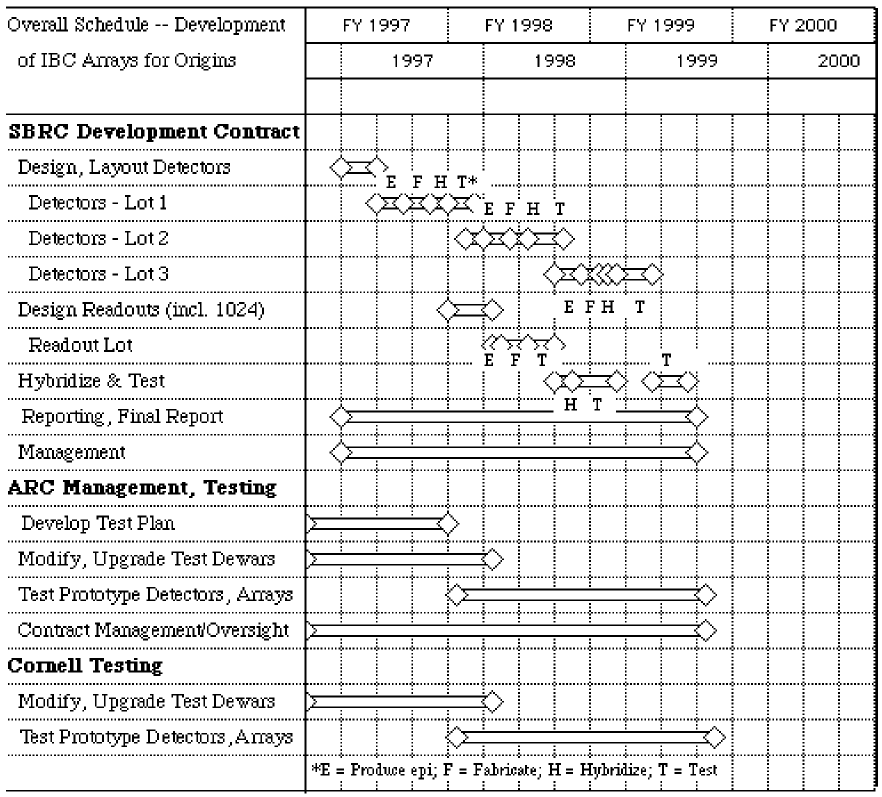
Multiple-Sampled Read Noise on IBC 65740 (June '97 Data)



Advanced Si:As IBC Arrays for NGST

Program Schedule

Contract award expected July ‘97; delays overall schedule ~10 months.



Summary

Si:As IBC array development program builds upon significant advances achieved for SIRTF / IRAC camera instrument

Includes focused research to understand and overcome performance-limiting factors

Uses excellent CRC-744 cryogenic readout (& derivatives)

Involves experienced development team, with supporting specialized lab capabilities

3-yr program, including three lots of detectors and readouts, aims to meet challenging NGST thermal-IR performance goals